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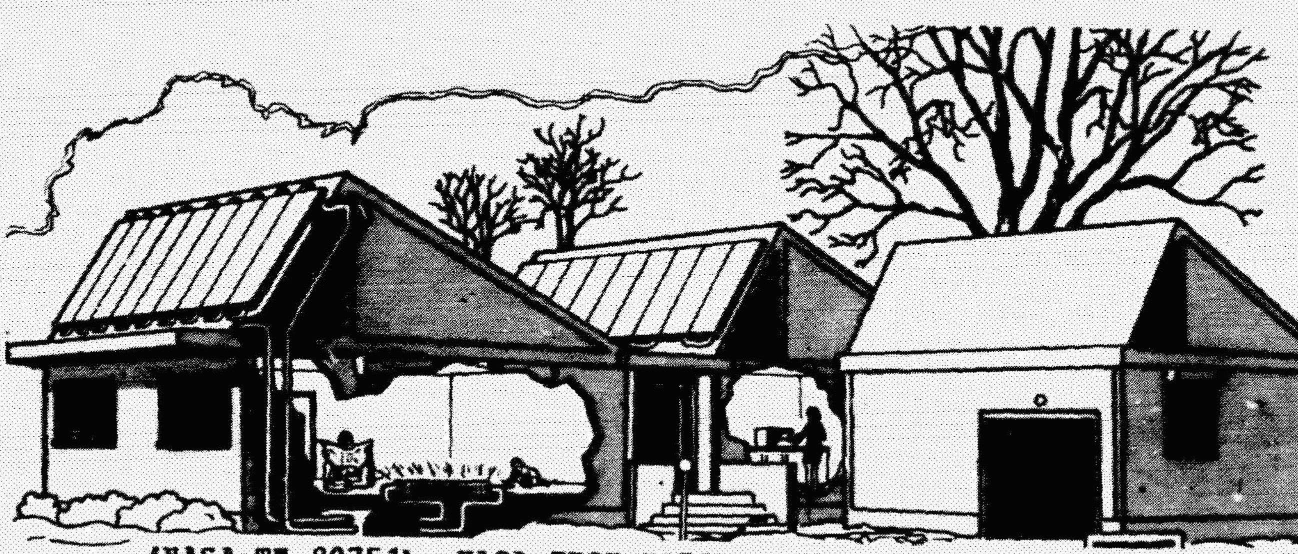
Technology Utilization Office

Tech House

An Early Evaluation



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NASA LANGLEY TECHNOLOGY UTILIZATION HOUSE

An Early Evaluation

CONTENTS

FOREWORD

This report contains early information on the operation and performance of some of the design features and energy systems of the NASA Technology Utilization House at Langley Research Center, Hampton, Virginia. In most cases, information has been obtained for limited operating conditions and final conclusions should be drawn only after further evaluation. The purpose of this report is to present the current operational status of the NASA Technology Utilization House systems and to provide some insight to the home building industry into the potential value of the ideas incorporated in the house design.

INTRODUCTION

The homebuilding industry is a blend of technology and economics. Most design and construction practices used today have been developed and refined over many years to enable designers and builders to provide homes in a wide variety of designs and sizes at a reasonable cost. The current consumer awareness of energy shortages and limited natural resources is providing an additional challenge to the industry to apply appropriate new technology as rapidly as is economically feasible. Builders and manufacturers, as well as the homeowner, must strive for new concepts which require less energy and resources.

Many ideas and concepts are being actively considered throughout the nation. Some of these approaches involve departures from what is generally considered the conventional single-family residence and lifestyle. Under the sponsorship of NASA, a committee was formed to determine any applicable new technology and systems design philosophy which would emphasize the conservation of energy and natural resources and, at the same time, be economically feasible for improving current design practices. The committee included representatives from the Department of Housing and Urban Development, the National Association of Home Builders Research Institute, the National Bureau of Standards, and the Consumer Product Safety Commission, as well as NASA personnel. Within this framework, an architect-engineer firm, as well as university participants, performed system studies, evaluated construction methods, performed cost effectiveness studies, and prepared construction drawings which incorporated the selected technology features into a final design. (See ref. 1.)

A Technology Utilization House (hereinafter referred to as the Tech House) based on this design was constructed at the NASA Langley Research Center in Hampton, Virginia. The Tech House is instrumented so that the performance of the design features and energy systems can be evaluated during a planned family live-in period. As such, the house is both a demonstration unit and a research laboratory.

Plans for the Tech House are available at the cost of $10.00 for reproduction, shipping, and handling from:

North Carolina Science and Technology Research Center
P.O. Box 12235
Research Triangle Park, North Carolina 27709
Telephone: (919) 549-0671

THE HOUSE DESIGN

Purpose

The purpose of the Tech House is to demonstrate the kind of single-family residence that will probably be available within the next five years. The house

applicable to the American home building industry. Specific objectives of this Technology Utilization project are:

1. To construct a single-family residence which will demonstrate advanced technology and which will minimize the requirements for energy and water services.

2. To help influence future development in home construction by combining energy and water management with building layout, new construction materials, and new technology systems.

3. To validate expected energy and water savings.

Guidelines

The technology considered for the design of the Tech House was of the kind which would provide recognizable benefits to the homeowner. Materials and systems were selected on the basis of energy efficiency and cost effectiveness. An item was considered cost effective if its initial cost plus 10 percent interest would be recovered through energy savings over the lifetime of that item.

From these broad considerations, more specific guidelines were developed. The Tech House was to be an attractive, economical, one-story home with 1500 square feet of living space plus an attached garage; it was to utilize technology that was either commercially available at the present time or that would be available within the next five years; its custom-made items were to be cost effective; it was to have a system of energy management within the house; it was to be built using modern practices in construction and in the installation of electrical and plumbing materials; it was to have a system for partial water reclamation and reuse; and it was to use solar energy for heating and for domestic hot water.

In addition, the final Tech House plan was carefully developed to take advantage of its geographical location. While not specifically discussed in this report, natural heating, cooling, and ventilation; landscaping; design and location of windows; angle for installing solar collectors; and other features are dependent on geographic location and climate conditions. Since these details are important in maximizing energy conservation, they should of course be taken into account for any similar houses in a different location.

Description

The contemporary design of the Tech House has the 1500 square feet of area divided between a living area and bedroom area that are connected by a flat-roofed hallway. The hallway provides front and rear entry to the house through double-door, air-tight vestibules, with the laundry room located in the rear vestibule. The connecting hallway uses a skylight which reduces the need for artificial light during the daytime and may be opened for ventilation. The

garage is similarly connected to the living area by a flat-roofed access hallway. The house is oriented to permit solar collectors to be mounted on the south roof of both the bedroom and living area portions of the house. If additional collectors were required (in other geographic locations, for example) they could be installed on the garage roof. The exterior of the house and the floor plan are shown in figures 1 and 2, respectively.

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Figure 1.- The NASA Tech House.

A broad range of selected technology items are incorporated into the design; included are solar energy; energy conservation items and systems; water conservation and reclamation techniques; security systems; fire resistant, safety materials and components; and NASA control and instrumentation technology. The following section briefly describes the energy and water conservation design items and systems (namely, the insulation, the solar heating system, the solar-assisted domestic hot water system, the fireplace, and the water conservation and reuse system) on which a quick-look performance evaluation has been made.

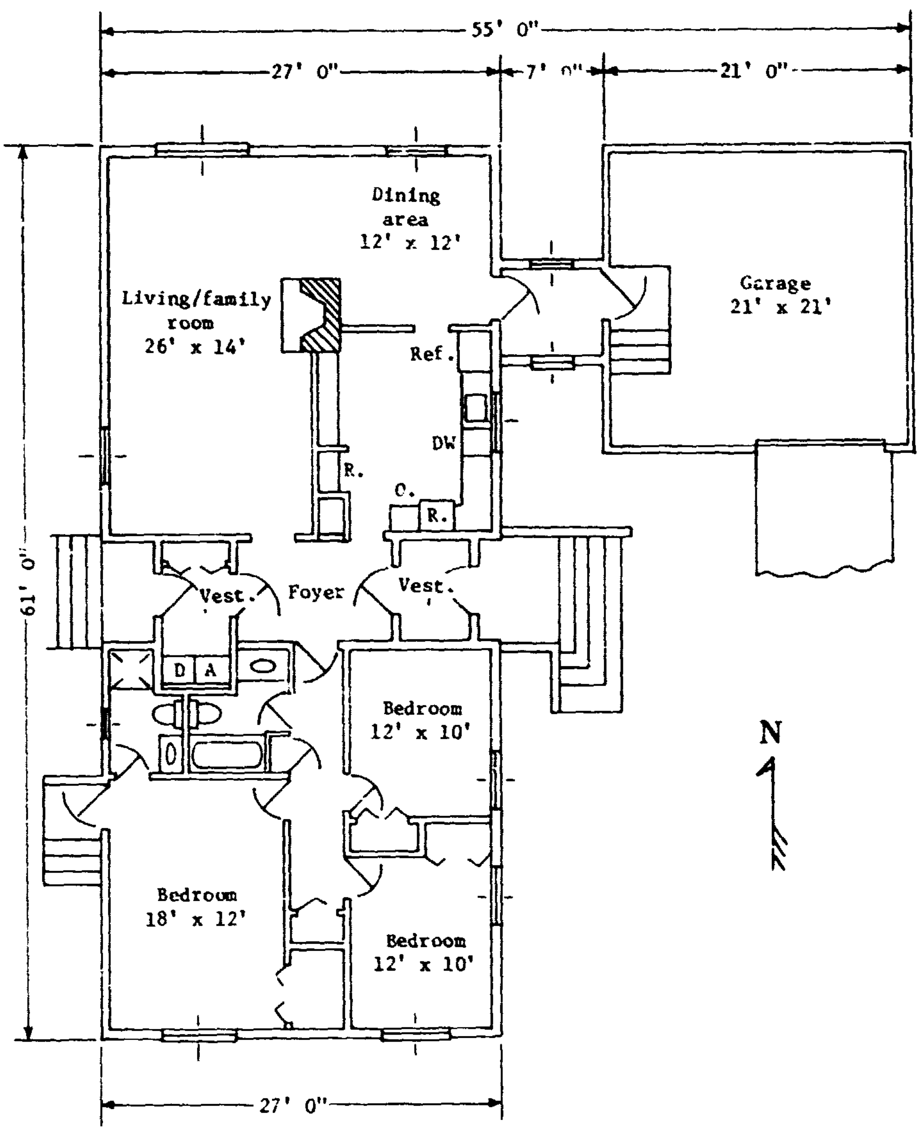

Figure 2.- The Tech House floor plan.

QUICK-LOOK EVALUATION

The following paragraphs present information from a quick-look evaluation of the insulation, the solar heating system, the solar-assisted domestic hot water system, the fireplace, and the water reuse system. Evaluation data are based primarily on measurements during February and March 1977 while the house was open to the public. General system descriptions and the respective evaluation procedures and performance observations are presented.

Insulation

Numerous features are used in the house design to minimize heat loss in the winter and heat gain in the summer. The exterior walls were constructed using 2 by 6 studs on 24-inch centers to provide space for 6 inches of exterior wall insulation. Urea-tripolymer foam insulation was used in both the ceiling and exterior walls; approximately $7\frac{1}{2}$ inches was used in the ceiling and $5\frac{1}{2}$ inches in exterior walls. The resulting approximate thermal resistances, or R values, are 34 and 25, respectively. It is estimated that the insulated ceiling will reduce heat loss by roughly 30 percent compared to the conventional 6 inches of fiberglass (R = 22), and that exterior wall heat losses will be reduced some 45 percent compared to the conventional $3\frac{1}{2}$ inches of fiberglass (R = 13). Floors in the house are prefabricated concrete with 6 inches of gypsum foam insulation. The dual door arrangements at the front and rear of the living area hallway serve as air locks to further reduce loss of heated or cooled air from inside the house when outside doors are opened. The window arrangement, including large windows, a roof overhang design feature on the south side, and operable shutters at all windows, is expected to result in additional energy savings through control of heat gain and heat loss.

Evaluation Procedure: Two types of short duration tests have been conducted during the period from 4 p.m. to 8 a.m. to correlate approximate existing heat losses with expected heat losses for the house as constructed. Long duration tests are not practical since the daytime visitor traffic through the house results in frequent door openings.

In one test, all heat to the house was turned off at the beginning of the evaluation period (4 p.m.) and the house was allowed to cool during the night. Temperatures inside the house and outdoors were recorded during the period. At the end of the cool-down (8 a.m.), the house was heated until the same constant temperature as existed at 4 p.m. the previous day was realized inside the house. The measured heat input plus a calculated infiltration heat loss quantity was assumed to be the total heat loss for the test period. The difference between the actual outside temperature recorded during the test and the design condition outside temperature was accounted for in the analysis of performance.

In the other test which was conducted during the same period of the day (from 4 p.m. to 8 a.m.), the heat required to maintain constant temperature within the house was measured. The total required heat measured was again adjusted in the performance analysis to compensate for the difference between the outside ambient temperature during the test period and the design condition outside temperature.

Performance: Although the test procedures described are not normally used to determine heat losses, they do provide a general, if not exact, indication of the insulation performance. When adjusted for design conditions, the first test indicated a heat loss of about 19,000 Btu/hour while the other test indicated a loss of about 22,000 Btu/hour; both compare favorably with the predicted design heat loss of 18,000 Btu/hour for a $53F^{o}$ difference between inside and outside temperatures.

While the heat loss tests were being conducted, a comparison was made of the electrical energy used by three available methods of heating the Tech House. During a one-hour period of operation, the same quantity of heat (about 16,000 Btu) was supplied to the house from three different heat sources — electric resistance heaters, the heat pump, and solar-heated water. To supply the same 16,000 Btu, the electric resistance heat element required 4.75 kilowatts, the heat pump required 2.25 kilowatts, and the solar-heated water required 0.5 kilowatts. While this comparison does not reflect initial cost or cost of ownership for the different systems, it does indicate the potential savings in operating cost for solar energy.

Solar Heating System

The Tech House heating system uses solar energy to provide most of the heating requirements. Key elements of the system are the roof-mounted flat plate solar collectors, a heat pump, a heat exchanger in the air duct which transfers heat from solar-heated hot water to air circulated in the house, a fireplace water coil, a well-water supply system, and the water storage tank. The house cooling system uses many of these same elements plus radiators to reject heat at night. The combination of these systems is shown in the simplified diagram of figure 3.

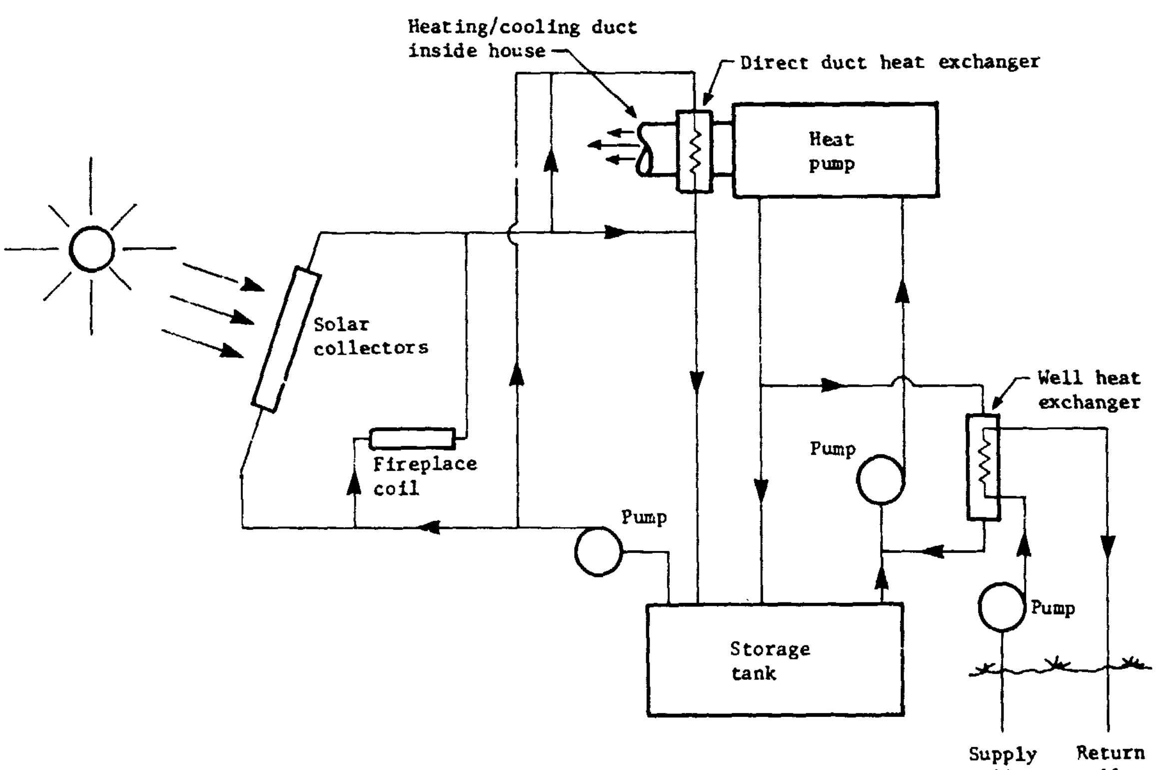

Figure 3.- Simplified diagram of heating and cooling system.

The solar collector area should generally be about one-third the floor area of a home that is insulated to 1974 FHA minimum standards to provide an average of 40 percent of the total heating in this geographical region. (See ref. 3, page 6.) However, because of the thermal design and insulation of the Tech House, 384 square feet (about 1/4 the floor area) is expected to provide about 80 percent of the heating. Sixteen 3- by 8-foot flat plate solar collectors are used with a black chrome absorber surface and a single glass cover. Collectors are mounted on the south roof at an angle of 58° to the horizontal. Water flowing through the panels is heated by the sun which, in turn, is used either to heat the house directly through the direct-duct heat exchanger or to raise the water temperature in the water storage tank where energy for use at nights and on cloudy days is stored. The storage tank is insulated and buried and has a 1900-gallon capacity. The tank was designed to store sufficient heat for up to $3\frac{1}{2}$ consecutive overcast days. The heat pump when operating in the heating mode transfers stored heat from the tank to the house.

For freeze protection of the collectors and piping system, the flow of water is automatically shut off and drained to the tank whenever the tank temperature is greater than the collector temperature. The solar collectors are also drained during periods of the year when the house does not require heating. Water circulated through the heating system is treated with chromates to inhibit corrosion.

Evaluation Procedure: The solar heating system has been used routinely to supply heat to the Tech House while it is being operated as a visitor tour site. Beginning in February and for the remainder of the 1977 winter heating season, for instance, it essentially supplied all of the heating requirements. With the large volume of visitor traffic, however, realistic system performance evaluation is difficult at best. From the early operational data, however, it has been possible to determine to what extent the solar collectors will provide the heating energy requirements for the house. The amount of solar energy collected is calculated from the measured rate of flow and rise in temperature of the water as it flows through the collector. Collector efficiency is the percentage of available solar energy that is collected in the heated water.

Performance: The data measured to determine the solar collector system performance are shown on an hourly basis in table I for a typical day of operation. The inlet temperature is representative of the water temperature of the storage tank and reflects heat remaining in the water from previous operation. As shown, the collectors added about 6F° to 10F° to that temperature in the early morning and late afternoon and over 20F° around midday for the flow rates indicated. The amount of solar energy collected compared to the amount available is shown graphically in figure 4. Approximately 380,000 Btu of solar energy was collected; this not only heated the house during the day time but was about 40 percent greater than the total 280,000 Btu required for the 24-hour day. Collector efficiency, collector outlet temperature, and tank temperature are plotted in the curves of figure 5. The increase in tank temperature reflects the increase in stored energy in the tank.

TABLE I.- SOLAR HEATING SYSTEM DATA

[Measured data for March 26, 1977]

Time	Outside temperature, °F	Solar radiation, Btu/hr/ft^2	Collector water flow, gpm	Collector	
				Inlet temperature, °F	Outlet temperature, °F
9 a.m.	44	185	6.14	116	125
10 a.m.	47	238	6.13	116	132
11 a.m.	50	272	6.21	117	138
12 noon	52	288	6.27	119	142
1 p.m.	56	280	6.20	121	143
2 p.m.	57	251	6.25	122	142
3 p.m.	50	203	6.25	123	136
4 p.m.	50	139	6.23	124	130

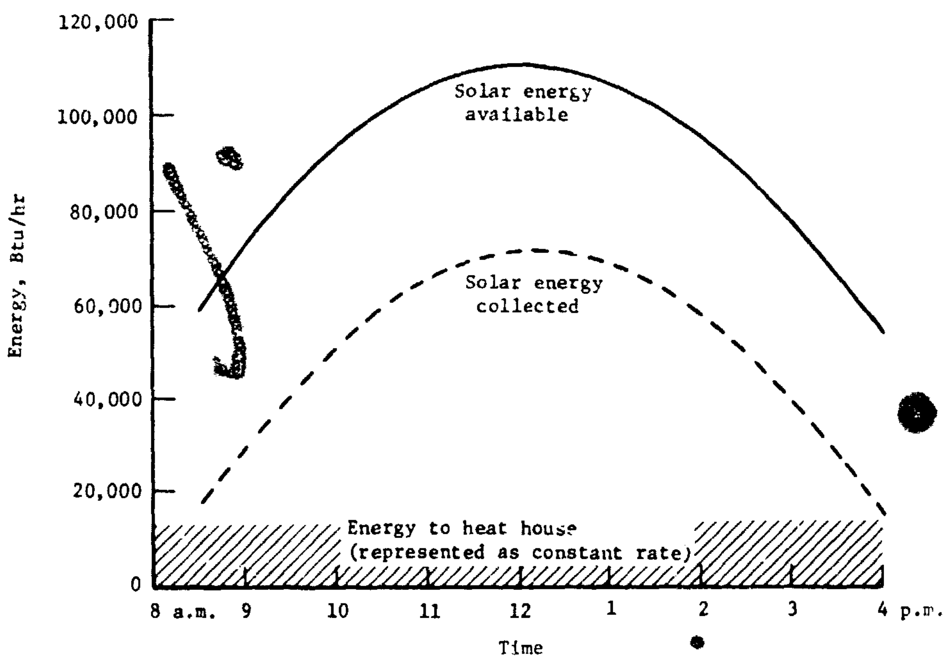

Figure 4.- Measured solar heating system data for March 26, 1977.

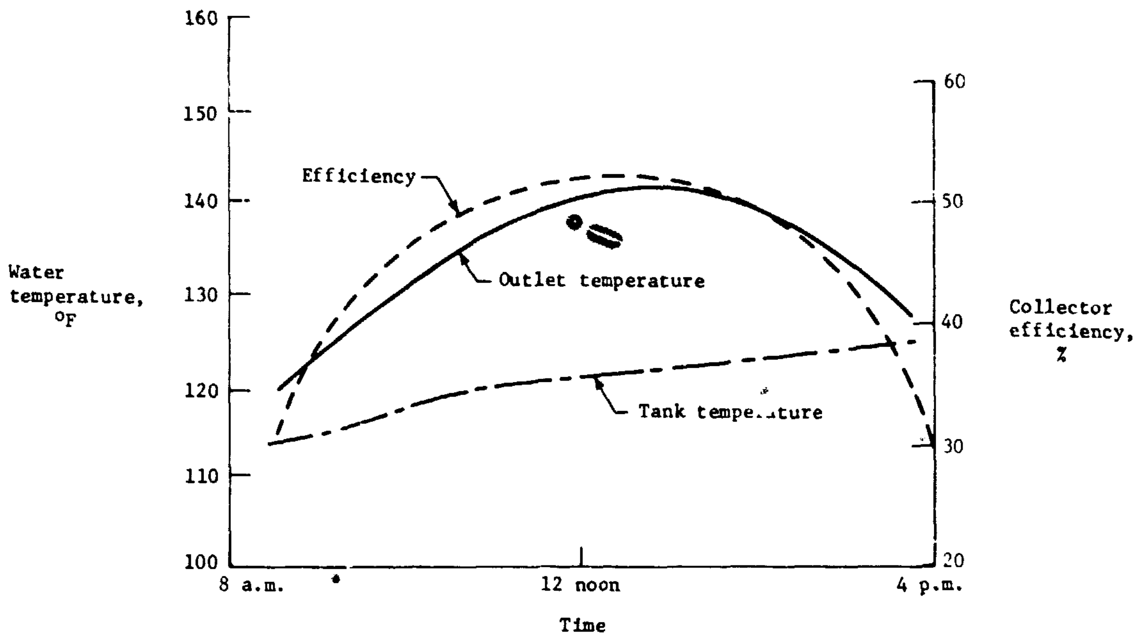

Figure 5.- Solar heating system performance data.

Based on these data and calculations performed prior to construction, it is estimated that the solar heating system will provide 70 to 80 percent of the annual heating requirements for the house.

Solar Domestic Hot Water System

Two of the roof-mounted solar collector panels at the Tech House are used year round to supply most of the energy needed to heat water for domestic use. The system includes a preheat tank and the conventional hot water tank, both of which are located in the access hallway connecting the garage to the living area. The preheat tank is wrapped externally with a heat exchanger coil that enables solar-heated water to preheat the incoming supply of city water. The water flowing in the solar collectors is treated with ethylene glycol (automobile antifreeze) for freeze protection. The collector loop includes 48 square feet of solar collectors (two, 3 by 8 units) which are the same type as those used in the heating system, the heat exchanger, and a circulation pump (fig. 6). As hot water is used within the home, water is transferred from the solar preheat tank to the conventional electric heater element domestic tank where it is heated further by electrical resistance heat if the temperature is below the thermostat setting. The important factor is that all solar-supplied energy at the preheat tank is a saving of electrical energy at the conventional tank.

The total solar system for domestic hot water and for home heating is shown schematically in figure 7.

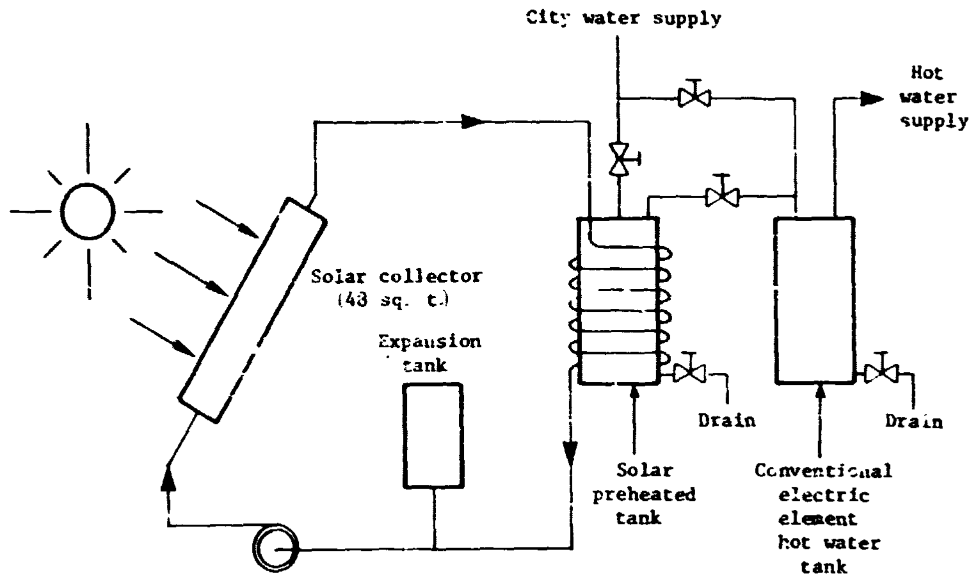

Figure 6.- Solar domestic hot water system.

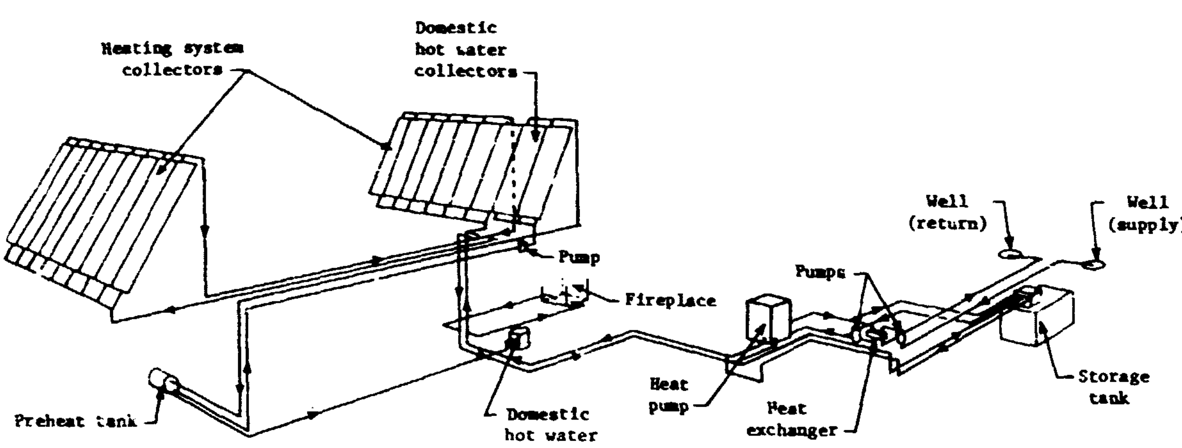

Figure 7.- Solar heating and domestic hot water systems.

Evaluation Procedure: Performance data on this system were obtained during the period that the water reuse system was being evaluated since both required a use of water based on estimates for a family of four. The data are based on a simulated typical day's use of 80 gallons of domestic hot water for the family.

On the day the measurements were made, the outside air temperature, the available solar energy, the collector panel water flow rate, and the collector inlet and outlet water temperatures were taken every half hour. From these measurements, total available solar energy, collected solar energy, and collector efficiency were calculated in the same manner as for the solar heating system evaluation. The measurements are presented in table II.

TABLE II.- DOMESTIC HOT WATER SYSTEM DATA

[Measured data for March 14, 1977]

Time	Outside temperature, °F	Solar radiation, Btu/hr/ft^2	Collector water flow, gpm	Collector	
				Inlet temperature, °F	Outlet temperature, °F
9 a.m.	63	83	0.76	96	101
10 a.m.	65	234	.79	108	126
11 a.m.	67	270	.82	122	142
12 noon	68	289	.85	138	157
1 p.m.	69	275	.86	141	162
2 p.m.	64	242	.85	138	155
3 p.m.	63	201	.82	120	136
4 p.m.	61	127	.81	116	122

Performance: The average day-long collector efficiency is similar to that for the solar heating collectors. It if felt that the mid-March performance presented is somewhat representative of the average for the whole year. Figure 8 shows the total solar energy collected compared to the simulated requirements which are shown, for convenience, as a constant value over the simulation period. It is important to note that, for some periods of the day, no electrical energy was required for domestic hot water. As shown, the solar collectors provide about 75 percent of the daily energy requirements.

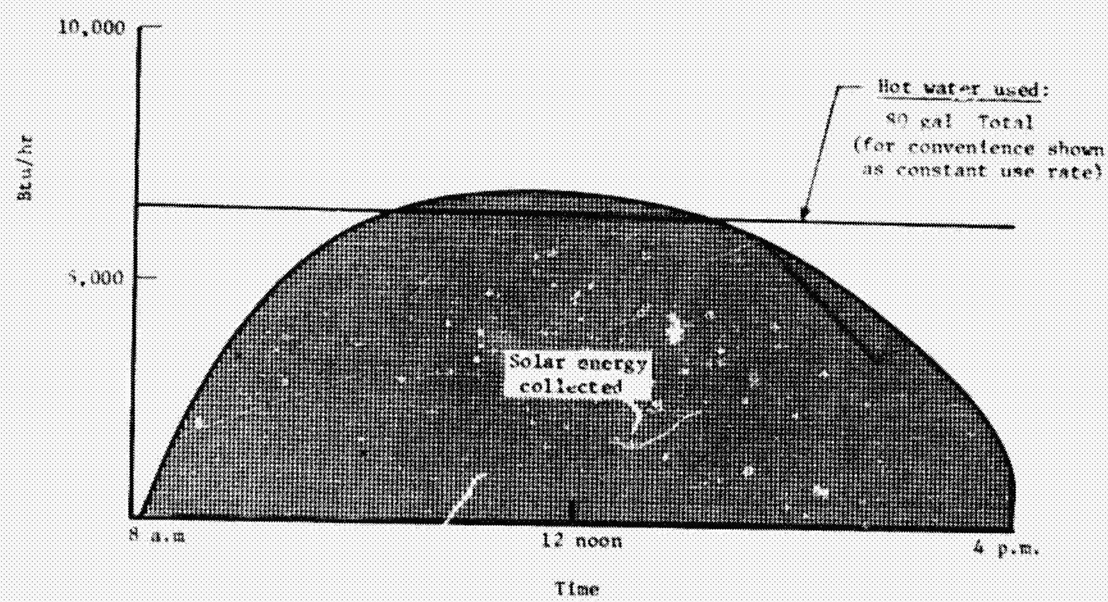

Figure 8.- Measured solar domestic hot water energy for simulated use.

Fireplace

The fireplace in the Tech House has design features intended to significantly improve efficiency over conventional types. Heat loss up the chimney is reduced by bringing outside air into the fireplace for combustion instead of using heated room air as is done in conventional fireplaces. The heating capacity of the fireplace is increased further by the use of a double wall metal firebox which allows some of the heat energy that is normally lost up the chimney to be returned to the living area. Finally, water is circulated through a fireplace grate water coil to collect additional heat and to either return it to the water storage tank or deliver it to the direct air-duct heat exchanger. These design features are expected to improve the fireplace efficiency about five times that of conventional types. Design features of the fireplace are shown in figures 9 and 10.

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Figure 9.- Fireplace as installed.

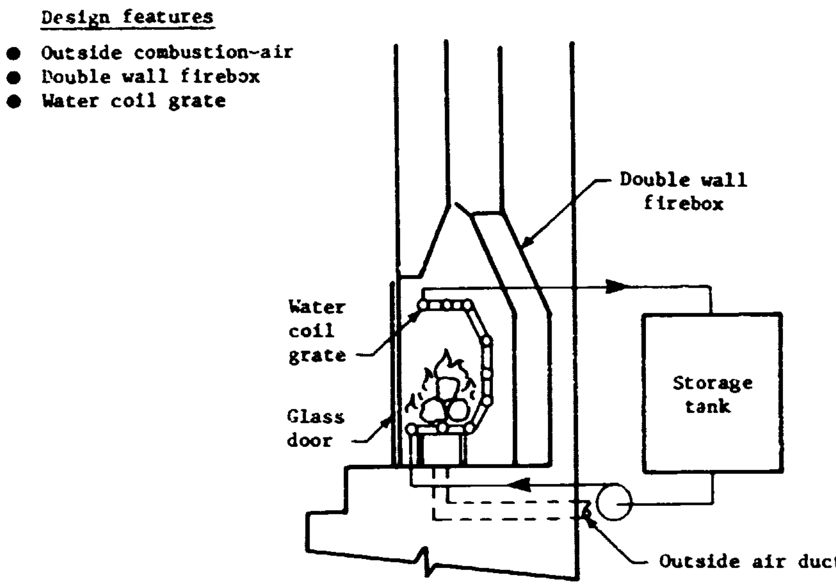

Figure 10.- Fireplace design.

Evaluation Procedure: The fireplace water coil has been operated to compare the measured improvement in efficiency with the expected efficiency. The evaluation was conducted over a three-hour period. Wood, as well as commercial prefabricated fireplace logs, was burned and the total heat produced was determined from standard calculations and manufacturers' data, respectively. The inlet and outlet water temperatures and flow rate for the fireplace water coil grate were recorded to enable the collected energy to be determined for a steadily burning fire.

Performance: Performance of the fireplace water coil is determined by relating the heat collected to the heat produced during the period the fireplace was burned. Summary data for the evaluation are presented in table III.

TABLE III.- FIREPLACE WATER COIL PERFORMANCE

Total energy produced by fireplace, Btu	116,000
Energy collected by fireplace water coil, Btu	43,000
Percent of energy collected	37

As shown, approximately 43,000 Btu of the total 116,000 Btu available was collected by the fireplace water coil for a performance efficiency of 37 percent.

The overall performance of the fireplace will be determined during the continuing evaluation. However, as indicated in table IV, the water coil heat exchanger is by far the major contributor to the expected overall gain from the improved fireplace design.

TABLE IV.- FIREPLACE PERFORMANCE

Item	Expected efficiency, percent	Measured efficiency data, percent
Conventional fireplace.	10	10
With water coil grate	Adds 30	Adds 37
With double wall firebox	Adds 10	---*
With outside combustion air	Adds 5	---*
Totals	55	---*

*Total evaluation delayed pending design optimization.

Water Reuse System

Technology developed by NASA for reuse of waste water has been installed in the Tech House. Waste water from the bathtub, shower, and laundry equipment is collected in a holding tank, chlorinated, filtered, and recycled for use as toilet flush water. (See figs. 11 and 12.) To complement this, other recently developed and marketed water saving fixtures are also included in the house (i.e., shower head flow restrictors and low profile water closets for commodes). The reuse system, along with water conservation fixtures, is expected to reduce the quantity of water used annually to about half that for a similar conventional home with a family of four.

Health and safety have been carefully considered in the water system. The drinking water system is entirely separated from the recycled water.

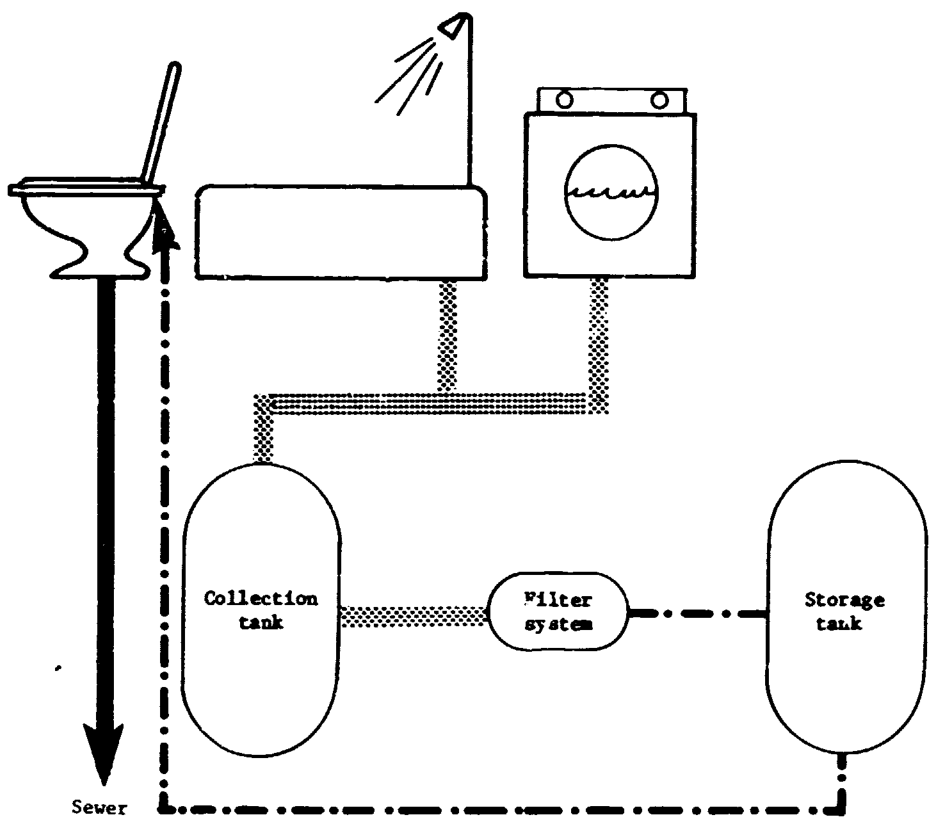

Figure 11.- Water reuse system.

Recycled water which is used to flush toilets, though not intended for consumption by human or animals, poses no known health hazards. All waste water from toilets goes directly to the sewer, as does any overflow from the reuse collection tank.

The overall reduction in water use has the additional potential benefit of reducing requirements for community sewage systems and treatment plants, as well as reducing basic requirements for water supply systems.

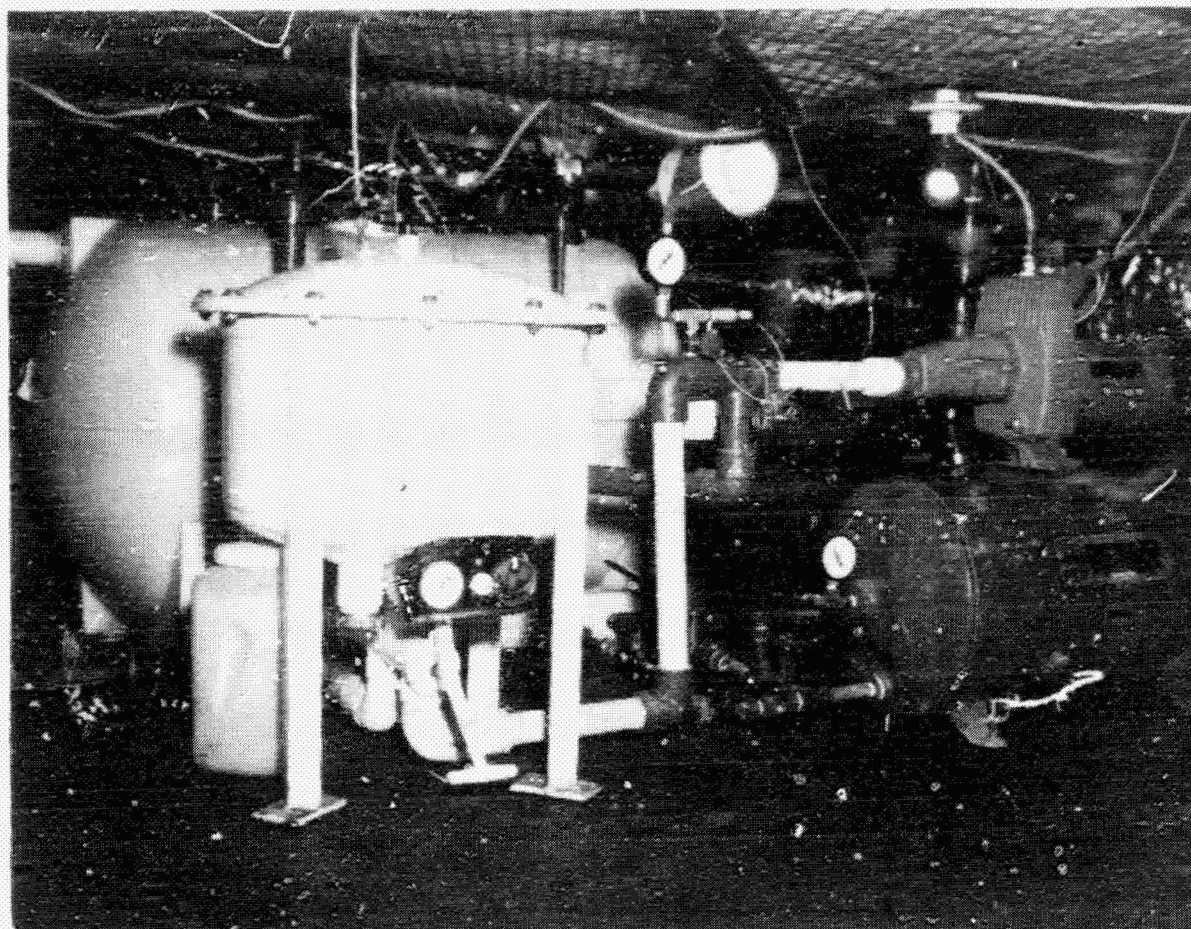

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Figure 12.- Water reuse system equipment located in crawl space of Tech House.

Evaluation Procedure: For evaluation of the water reuse system, a simulated living pattern was created over a three-week period during February and March 1977. Two showers were taken daily, one in the morning and one in the afternoon. Soiled clothing as produced by a family of four was laundered during the evaluation period. Waste water was collected daily, except on weekends. The number of commode flushes was also recorded. Water use was recorded each morning to provide a record of use for the previous day.

Water samples for microbiological analysis were taken from the collection tank and from each of the bathroom commode water closets. At the beginning of the test, samples were taken from each of the three locations to compare with samples later in the test. For these initial samples, the system was filled only with tap water from the makeup water line. During the three-week test period, samples were collected daily to provide a history of the microbiological characteristics of the system for the simulated use pattern.

Chlorination was used as the microbiological control technique. The chlorine solution (chlorine bleach) mixture rate was reset when necessary to provide a constant rate of chlorine addition.

Simultaneous with the daily ollection of the microbiological samples, an additional sample was collected from the hall bathroom commode water closet and evaluated for the presence of free chlorine and the presence or absence of a chlorine or "laundry" odor. An analysis of these characteristics aids in the evaluation of the chlorination rate.

Energy used by the system jet pump was recorded, as well as data on the frequency and duration of pump operation.

Performance: During the three-week period, 775 gallons of flush water was used. Makeup water provided 63 gallons of that amount. Thus, 92 percent of the required flush water was provided by reclaimed waste water and 8 percent by makeup water. These percentages, however, are more a function of the simulated family living pattern than of system performance. The system will use all the waste water available except that which is lost during an overflow from the collection tank.

The microbiological analysis indicated a total "kill" of all organisms during the first week of the evaluation period. The residual free chlorine counts sampled in one commode water closet, however, were much too high; thus an overchlorination with a resulting chlorine odor in all the water samples was demonstrated.

At the end of the first week, the chlorination level was reduced to the slowest addition rate possible with the control valve that was utilized. At the beginning of the second week the chlorine bleach was diluted (1 part chlorine bleach to 4 parts tap water), which resulted in a chlorine bleach use rate equivalent to one gallon of chlorine bleach every 3 months. This rate proved adequate to control the most important of the microbiological organisms, the fecal coliforms. Control was adequate in the collection tank and in both commode water closets.

The electric meter for the pump was operational during the last two weeks of the evaluation period. The data show that the pump was on an average of 4.7 minutes a day and used power at an average rate of 850 watts when running; this resulted in an average electrical energy use of 0.07 kilowatt-hours a day.

It was expected that the system filter might become contaminated with residue and that the pump suction (vacuum) and running time would increase. At the end of the three week period, however, neither the pump suction nor the running time had increased. Thus, the filter had indicated no degradation in performance during this limited period of operation.

Performance of the water reuse system was as expected during the three week test period and the system is adequate for use as installed. Available technology for improvements to the chlorination technique will be applied as practical.

CONCLUDING REMARKS

This report reviews the Tech House design and technology features and presents a quick-look evaluation of the solar energy systems, the water reuse system, and other general design and energy conservation features of the house. The performance data are based on short duration periods of evaluation that could be achieved with minimum interference to vistors touring the house. The preliminary evaluation has also helped identify system and operating modifications that will be made prior to the planned family live-in evaluation period.

Measured performance of the solar heating system and the solar domestic hot water system indicates that 70 to 80 percent of the annual heating requirements and approximately 75 percent of the energy for domestic hot water should be supplied by solar energy. The water coil heat exchanger used in the fireplace improves performance by a factor of 3 to 4 over conventional fireplaces. Results from the water reuse system evaluation show that the system can approximately halve the water requirements and is satisfactory for use as installed. Some improvements are being made, however, based on information gained from the evaluation.

Evaluation of the Tech House systems and design features and detailed analysis of the incorporated energy and conservation technology is a continuing process. The data recorded during the one-year family live-in period will, of course, provide the basis for a complete evaluation of all aspects of this house concept.

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